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Evaluating roughness of logging haul roads within the Monongahela National Forest

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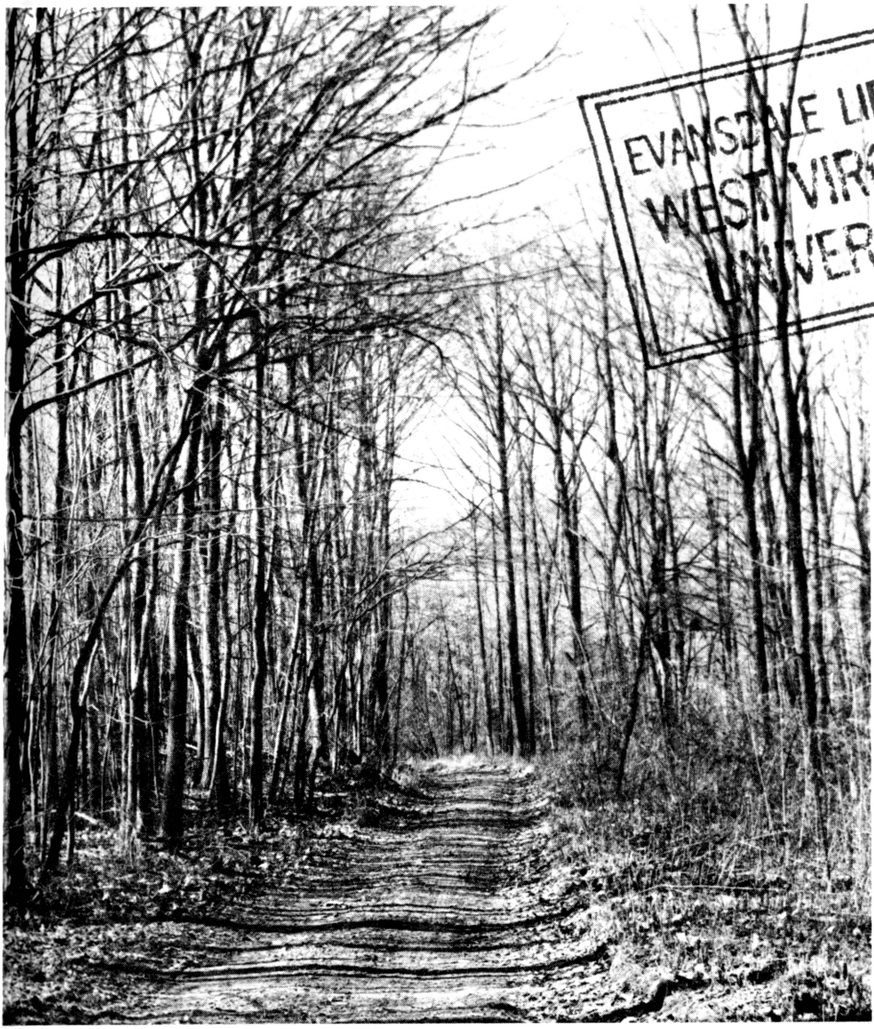

AUTHORS

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Evaluating Roughness of Logging Haul Roads

Within the Monongahela National Forest

Michael R. Sprouse, Kenneth L. Carvell, Penn A. Peters, and Gary D. Falk

INTRODUCTION

In the eastern United States, as in other parts of the country, what constitutes cost effective logging haul road design, layout, and construction is a popular subject for discussion. There are advocates for lower standard roads than those that exist in many of the National Forests, desiring to minimize the initial cost of the road while accepting the possibility of higher maintenance and hauling costs. A popular, low cost construction technique in the East is the use of broad based dips to control drainage instead of ditches.

In an attempt to contribute to this discussion a field survey of a selection of logging haul roads within the boundaries of the Monongahela National Forest was conducted in the summer of 1980. A measure of roughness of the road cross section was defined to permit a comparison of "goodness" of road cross sections and road segments included in the field survey. The influence of road design parameters on cross section roughness is presented. Limitations of cross section roughness as a measure of "goodness" of a road segment are discussed.

LITERATURE REVIEW

Cook and Hewlett (1979) found that the best location for woods roads in the Piedmont was along the shoulder of a ridge where deep cuts were not required. Pearce and Stenzel (1972) concluded that ridge-crest routes had construction and drainage cost advantages, but required stretches of adverse gradient and a longer haul. According to Kochenderfer (1970) and Pruett (1975), roads located on hillsides provide better drainage.

Vertical and horizontal alignment are two important factors to consider when constructing roads. Hewlett and Douglass (1968) suggested that grades not exceed 13 percent and that no curve should have a radius of less than 25 feet. Groves et al. (1979) supported avoiding grades of less than 3 percent to decrease surface drainage and stabilization problems. *The West Virginia Guidelines for Controlling Soil Erosion and Water Pollution* (Anonymous n.d.) state that grades should be 10 percent or less, but that gradients up to 15 percent are allowable for distances up to 200 feet.

Culvert spacing receives considerable attention when constructing haul roads. Groves et al. (1979) supported using culverts 18 inches or larger in diameter and reported maximum culvert spacing for a given percent grade (Table 1).

Kochenderfer and Wendel (1980) reported that cut banks should not be sloped, since sloughing and stabilization will eventually occur naturally. Table 2 presents Groves et al. (1979) recommendations for maximum slopes of cut and fill banks according to the type material and road class.

Table 1
Maximum spacing for culverts 18 inches in diameter or greater. (Groves et al. 1979).

Percent Grade	Maximum Spacing (Feet)
0–4	1,000
4–6	800
6–8	600
8–10	400
10+	300

Table 2
Recommended maximum slopes of cut and fill banks (Groves et al. 1979).

Cut/Fill	Type Material	Road Class*		
		I	II	III
Cut Banks	Rock	¼:1	¼:1	¼:1
	Shale or stable soil	1:1	1:1	1:1
	Unstable soil	1½:1	1¼:1	1:1
Fill Banks	Rock	1:1	1:1	1:1
	Soil	1¼:1	1¼:1	1¼:1

*Road Class
I-Road length of 5 miles plus, and a maximum safe speed of 35 mph.
II-Road length of 3–5 miles and a maximum safe speed of 25 mph.
III-Road length of 1–3 miles and a maximum safe speed of 15 mph.

The amount of daylight a road receives influences how rapidly the road will dry. Gardner (1978) remarked that increased road width helped roads to dry faster as well as providing truck drivers with longer sight distances.

Monteith (1978) described the running surface of a road in terms of the frequency that columns, rills, and gullies occurred. Craul (1976) developed six classes of surface rut ranging from ruts less than 10 cm. deep to ruts equal to or greater than 20 cm.

LOCATION AND DESCRIPTION OF STUDY AREA

The study area was located within the northern half of the Monongahela National Forest in eastern West Virginia. The roads evaluated were located west of the Allegheny Front on the unglaciated Allegheny Plateau which is made up of steep, rugged mountains separated by narrow valleys. All road segments evaluated were located in Tucker, Randolph, or Pocahontas counties.

Many miles of roads were constructed from 1933–1942 during the life of the Civilian Conservation Corps. Then during World War II construction of roads was made the responsibility of the timber operator, and construction specifications were included in the timber sale contract (McKim, 1970).

Today there are 600 miles of roads within the Monongahela National Forest that are maintained by the U.S. Forest Service. Only 20 miles of this total are double lane with the remainder being 10–12 feet wide and of variable design and surface composition (USDA, Forest Service, 1977).

DATA COLLECTION

Twenty-four Forest Service road segments and ten Mower Lumber Company road segments within the boundaries of the National Forest were evaluated. Not all variables that influence the stability of the road surface were taken into consideration. Variables that were constant for a road segment such as age, soil type, geologic structure, length of time since maintenance, average yearly precipitation, and amount and type of use were not considered. Field variables which had different values from one cross section to the next within a road segment were considered.

Methods were developed in this study to measure the field variables and reduce these data to a form that could be analyzed statistically. Field data were collected by a three-person crew during the period June–August, 1980. In the field, the priority number of the road, date, and a description of the exact location of the road segment were recorded. After driving the road segment, condition of the road surface was described as a 1, 2, or 3 with 3 being the best condition class. This rating was later compared with the mean roughness for the road segment, obtained from the reduced data.

The footage of each road segment was obtained by rolling a wheel with an odometer attached to it down the middle of the road. The footage was recorded at every 150 feet and at the beginning point of a road, beginning of a curve, end of a curve, point of reverse curve, point of compound curve, changes in grade, and at culvert locations. A staff compass mounted on the frame of the footage wheel was used to obtain the direction of tangents going into and coming out of a curve. The direction of these tangents and the length of the arc from the beginning to the end of a curve were used to obtain the radius of curvature. A relaskop was used to obtain percent grade from one stop to the next. Care was taken to include changes in grade.

Cross section measurements were taken every 150 feet. There were as many as 40 cross section measurements for a road segment depending on its length. The thirty-four road segments ranged in length from 1,401 feet to 6,522 feet. At each cross section the road was described as a through cut, through fill, having the cut bank to the right, or the cut bank to the left. Length, angle in degrees, and condition of each cut and fill bank were recorded. Assigning a condition to a bank was subjective, and condition of the banks ranged from 1 to 3, with 3 being the best.

Daylighting data were also obtained at each cross section. The angles in degrees to the highest obstruction in the east, south, and west directions were recorded. The angle for a given direction was found by focusing a relaskop at the top of the object that protruded the highest. For example, the object could have been a tree ten feet from the road edge or a ridge a mile away.

Slope position at each cross section was assigned a value of 1, 2, and 3 respectively to denote a valley-bottom, mid-slope, or ridge-top position. Aspect was also obtained and was defined as the direction toward which the slope faced. Cross drainage data included the location (footage) of each culvert encountered. Culvert spacing was obtainable from these data.

A special piece of field equipment was constructed to aid in measuring the roughness of the road surface (Figure 1). This "dowel jig" consisted of 62 wooden dowels, 3 feet long, which passed through holes bored 1.5 inches apart through an 8-foot crosspiece constructed of wood.

Figure 1. Dowel jig used for measuring the roughness of the road surface.

At the beginning of the data collection period, an attempt was made to utilize a 16-foot section of dowel jig. The dowel jig was attached to the back of the truck and was raised and lowered by a set of pulleys and cables. The 16-foot section consisted of four 4-foot sections connected by hinges. Use of this apparatus was discontinued due to the difficulties involved with raising and lowering the apparatus. The 8-foot section which was carried by two crew members was more efficient and could be moved out of the way of traffic with less difficulty. At each cross section the dowel jig was placed perpendicular to the road with one end at the road margin on the fill slope side. A level bolted to the crosspiece of the dowel jig provided a means of leveling the crosspiece. The tops of the dowels defined the configuration of the road surface. After a photograph was taken, the dowel jig was moved so that the end that had been at the road margin was at the point where the far end of the jig reached previously, and another photograph was taken.

If a ditch was reached and less than 8 feet of road cross section remained, then a dowel, painted black, was placed in the jig at the point to which the last dowel jig setting reached to avoid adding the overlap to the width of the road. The black dowel contrasted with the other dowels which were painted orange. For this final photograph of the road cross section, a black dowel was placed at the edge of the road so that road width could be easily determined from the photographs. Since the photographs included profile of the ditch, data on the volume of water that a ditch is able to handle was made available. This process was repeated at each 150-foot cross section.

Data Reduction

Reduction of the dowel jig data involved projecting the negatives of the photographs for a given road cross section onto the screen of a digitizer. The top of each dowel was digitized and entered into data storage in a desk top computer. A regression line was run through the points. The sum of squares of the deviations of the points from the regression line was obtained and divided by the number of points. The square root of this value was defined as the roughness of a particular road cross section.

Radius of curvature in feet for any given point on a road segment was obtained from horizontal alignment data. The reduced data also made it possible to plot the horizontal alignment of a road segment.

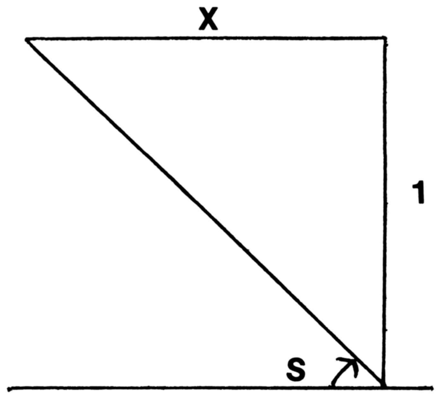
Aspect was described as right, left, front, or back in the field at each cross section. The reduced horizontal alignment data were used to find the tangent to any point on the road segment. Aspect was then obtained by manipulating the direction of the tangent by 0, ±90, or 180 degrees.

Daylighting data measured in the field were a vertical angle and a horizontal distance for the east, south, and west directions. The angle measured was from eye level (assumed 5 feet) to the highest obstruction. The distance recorded in the field was an estimate of the horizontal distance from the observer to the obstruction. The distance measure was used to adjust the angle observed from eye level to the angle as seen from the road surface. To obtain the reduced daylighting figure, adjusted angles were inserted into the following equation:

$$\text{Daylighting} = \frac{1}{2\ \text{TAN South}} \left(\frac{1}{\text{TAN East}} + \frac{1}{\text{TAN West}} \right).$$

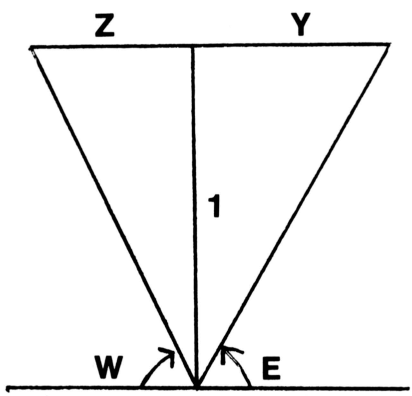
The higher the value obtained, the greater the amount of sunlight reaching the cross section. The daylighting value represents the area of a triangle above the road surface, through which sunlight passes. Figure 2 illustrates how the daylighting equation was derived.

It was thought that the roughness of a cross section might be influenced by the distance to the nearest cross drainage upslope from the cross section. Percent grade data and culvert footages were used to determine the distance to the nearest cross drainage. For example, if the grade taken at a cross section was greater than zero, then the distance to the nearest cross drainage was equal to the footage at the next cross drainage to be encountered less the footage at the cross section.



(a) Side view of the angle to the south.

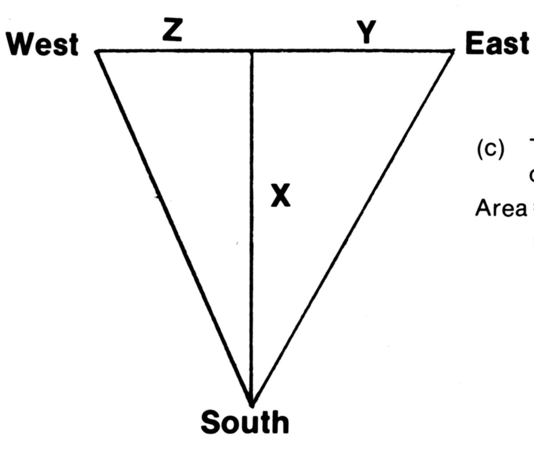
$$X = \text{COT } S = \frac{1}{\text{TAN } S}$$



(b) Side view of angles to the east and west.

$$Y = \text{COT } E = \frac{1}{\text{TAN } E}$$

$$Z = \text{COT } W = \frac{1}{\text{TAN } W}$$



(c) Top view of daylighting triangle.

$$\text{Area} = \tfrac{1}{2}\, X\, (Y + Z) = \tfrac{1}{2}\, \text{COT } S\, (\text{COT } E + \text{COT } W) = \frac{1}{2\,\text{TAN } S}\left(\frac{1}{\text{TAN } E} + \frac{1}{\text{TAN } W}\right)$$

Figure 2. Derivation of the daylighting equation. The height of the daylight triangle above the road surface is assumed to be one arbitrary unit.

Analyses and Results

Means of all variables measured at every 150-foot cross section were calculated for each road segment. Table 3 presents means for both Forest Service and Mower Lumber Company road segments.

Late in the study, it was discovered that the definition of roughness used gave high values of roughness for smooth, well-crowned road segments. It is expected that this undesirable result could be eliminated by fitting a parabola instead of a straight line to the road cross sections. It was not possible to do this within the study time frame. For a temporary correction, all road segments that had a crowned surface were excluded from further statistical analyses. These included the following: RF02, RF03, RF07, RF39, FF07, FF08, and MO01.

The remaining road segments were classified (Table 3) as: in-use Forest Service roads, retired Forest Service roads (seeded or having waterbars), or Mower roads. The mean roughness coefficients were 0.0666, 0.0916, and 0.0580, respectively, for the three groups. The Mann-Whitney rank sum test was employed to show that at the 0.01 level of significance, retired Forest Service roads were rougher than in-use Forest Service roads and Mower roads, but that while the mean roughness of in-use Forest Service roads was greater than the mean roughness of the Mower roads, the differences were not significant.

A multiple regression was the next method of statistical analysis used on the data. The dependent variable was roughness of each road cross section. Four variables were created before the best model was found. Created variables included differences between road segments, condition of the fill bank, condition of the cut bank, and straight. Straight was a classification variable that dealt with radius of curvature. It consisted of two levels. One level was called curved and included observations that had a radius of curvature of 0 to 3,200 feet. The other level was called linear and included observations with a radius of curvature of 1,000,000 feet or more. Differences between road segments, condition of the fill bank, condition of the cut bank, straight, and slope position were treated as classification variables. Absolute value of grade was the only continuous variable used in the model. This model yielded an R-square value of 0.322 with differences between road segments and condition of the fill bank contributing significantly at the 0.01 level. Straight and absolute value of grade were significant at the 0.05 level. The differences between road segments alone accounted for 28 percent of the variation. Table 4 gives the results of this regression model.

After driving a road segment for the first time, an estimate was made of the roughness of the ride before any data were collected. The road segment was described as a 1, 2, or 3, with 1 being assigned to the roughest road segments and 3 to the least rough road segments. The mean estimated ride roughness was 1.63 for the Forest Service road segments and 1.43 for Mower Lumber Company road segments. This agrees with the general impression of the authors that the Mower road segments were rougher-riding overall. However, this contradicts the means for the calculated roughness from road cross sections, which were 0.0666 for in-use Forest Service road segments and 0.0580 for Mower road segments.

A few possible explanations for this follow. First, the roughness measure that was used measured roughness across the road, but not down the length of the road. Therefore, washboarding did not show up in the roughness measure. Also, ride roughness associated with abrupt grade changes of broad-based dip designed roads does not show up in cross-section roughness.

Table 3
Means of Forest Service and Mower Lumber Company road segment variables. Abbreviations used are explained in Appendix Table 1.

Road*	Class**	Rou	Rad	Asp	Agra	Angl	Angr	Conl	Conr	Day	Dcross	Spos
RF01	Retired	.0956	200,304	267	7.1	36	35	3.0	2.9	0.490	***	2.0
RF02	Crowned	.0734	201,108	132	2.6	30	32	3.0	3.0	0.561	232	2.0
RF03	Crowned	.0728	162,169	170	2.6	34	37	3.0	2.9	1.161	188	2.0
RF04	Rerired	.0511	400,315	279	3.2	37	31	3.0	3.0	0.688	353	1.0
RF06	In Use	.0808	243,769	215	6.4	33	30	3.0	3.0	1.429	***	2.0
RF07	Crowned	.0872	230,389	245	5.5	37	35	3.0	3.0	0.827	177	2.0
RF08	In Use	.0594	144,452	172	2.6	35	34	3.0	2.9	1.045	299	2.1
RF09	In Use	.0737	429,271	183	5.2	20	20	3.0	3.0	1.984	943	3.0
RF10	In Use	.0675	371,736	174	3.9	32	30	2.8	2.9	0.309	314	2.3
RF12	Retired	.1154	187,946	127	8.5	37	37	2.9	2.9	0.297	837	2.0
RF21	Retired	.0893	264,897	226	7.1	27	32	3.0	2.9	0.166	382	2.1
RF23	Retired	.0950	193,973	153	7.1	31	41	2.9	2.6	0.426	***	2.0
RF24	In Use	.0701	466,834	115	7.7	35	27	3.0	2.9	0.230	164	1.4
RF27	Retired	.0846	300,320	197	5.6	20	42	3.0	2.7	0.141	1060	2.3
RF37	In Use	.0842	350,404	147	6.3	25	26	2.9	2.9	0.234	***	2.8
RF39	Crowned	.0609	57,925	171	4.1	30	27	2.9	2.9	0.084	228	2.8
RF40	In Use	.0790	1,255	103	5.8	42	36	3.0	3.0	0.288	***	2.4
RF46	In Use	.0567	257,666	257	4.3	27	25	3.0	3.0	0.100	226	2.7
FF02	In Use	.0620	118,016	236	5.4	41	28	2.7	2.9	0.546	457	2.2
FF05	Retired	.1099	222,245	313	9.2	39	38	2.7	2.7	0.618	***	2.0
FF07	Crowned	.1076	200,695	234	3.6	46	37	2.7	2.9	1.797	348	2.0
FF08	Crowned	.1160	108,000	256	8.5	38	33	2.9	2.9	1.831	102	2.1
FF10	In Use	.0475	154,091	207	5.4	56	34	1.4	3.0	1.115	98	2.3
FF13	In Use	.0514	40,704	106	9.2	45	43	2.5	2.9	1.164	149	2.4

MO01	Crowned	.1128	38,150	121	2.4	36	30	3.0	3.0	0.385	419	2.0
MO02	Mower	.0632	111,785	143	5.3	36	34	2.9	3.0	0.608	984	2.7
MO03	Mower	.0632	148,558	145	2.9	34	31	3.0	3.0	0.785	1116	3.0
MO04	Mower	.0636	269,905	228	7.7	40	35	2.3	2.9	0.823	220	2.0
MO05	Mower	.0487	111,943	35	6.1	40	38	2.9	2.5	0.615	***	2.0
MO06	Mower	.0423	185,628	113	2.1	26	24	2.9	3.0	0.824	725	1.0
MO07	Mower	.0543	231,648	155	3.0	33	25	2.8	3.0	0.677	1367	1.6
MO08	Mower	.0520	240,474	137	1.9	37	29	3.0	3.0	0.642	465	1.3
MO09	Mower	.0710	296,598	155	4.3	24	43	3.0	2.6	0.537	560	2.0
MO10	Mower	.0642	185,843	197	4.4	41	33	2.2	2.7	0.814	393	2.0

*Sprouse (1981) gives the exact location of these road segments.
**Crowned roads were dropped from statistical analysis. In use and retired refer to Forest Service road segments.
***No data were available.

Table 4
Results of the multiple regression model.

Variance Source	DF	SS	MS	F
Road	26	0.19299	0.00742	10.91**
Filcond***	3	0.01548	0.00516	7.59**
Straight	1	0.00310	0.00310	4.56*
Spos	2	0.00022	0.00011	0.16
Cutcond	3	0.00310	0.00103	1.51
Agra	1	0.00282	0.00282	4.09*
Error	668	0.45790	0.00069	

*Significant at 0.05 level.
**Significant at 0.01 level.
***List of abbreviations given in Appendix Table 1.

A multiple regression performed indicated that 28 percent of the variation in cross-section roughness was due to the differences between road segments. Variables such as age of the road segment, soil type, geologic structure, length of time since maintenance, average yearly precipitation, and amount and type of use would probably help explain variation due to differences between road segments.

Of all variables measured, only a few contributed significantly to the model for cross-section roughness. Condition of the fill bank contributed significantly at the 0.01 level. If the fill on which part of the road cross section is located is in poor condition, then the road surface would also be expected to be in poor condition. Actually, condition of the road banks could be thought of as being dependent variables, since their condition is influenced by many of the factors that influence the condition of the road surface.

Radius of curvature is an important factor when comparing small radii of curvature (0 to 3,200 feet) with relatively large radii of curvature (1,000,000 feet or more). Road cross sections were rougher in the curves than they were in the straight segments. The absolute value of grade was significant at the 0.05 level. As one might expect, the steeper segments tended to have rougher cross sections.

Conclusions

Road cross-section roughness was used as a quality measure of the road surface condition in a comparison of 34 road segments located within the Monongahela National Forest. Roughness was defined as the square root of the mean sum squared error from a regression line fitted through the profile of the road cross section.

Using the definition of roughness used in this study, the following conclusions were made.

Road curves are rougher than straight road segments.

The steeper the road grade, the rougher the road surface.

Retired roads are rougher than active roads. This is primarily due to rutting.

Twenty-eight percent of the variation in road cross-section roughness is due to differences between road segments. Age of road segment, soil type, geologic structure, length of time since maintenance, annual precipitation, and amount or type of use all help to explain this variation between road segments.

The following limitations of road cross-section roughness were noted. Road roughness was not a good measure of quality of ride. Washboarding and abrupt grade changes (broad-based dips) which resulted in a bumpy ride did not show up as high as roughness values. Also, smooth, well-crowned roads were indicated to be rough because a straight line was fitted to road profile. It is believed this latter limitation could be eliminated by fitting a parabola to the road profile before calculating roughness.

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APPENDIX
TABLE 1.
Abbreviations used in text.

Term	Abbreviation
Absolute Value of Grade (Percent)	Agra
Angle of the Left Road Bank (Degrees)	Angl
Angle of the Right Road Bank (Degrees)	Angr
Aspect (Degrees counterclockwise from due east)	Asp
Condition of the Left Road Bank	Conl
Condition of the Right Road Bank	Conr
Condition of the Cut Bank	Cutcond
Daylighting	Day
Distance From Cross Drainage (Feet)	Dcross
Condition of the Fill Bank	Filcond
Radius of Curvature (Feet)	Rad
Roughness of Road Surface	Rou
Slope Position (1=Valley, 2=Midslope, 3=Ridge)	Spos
Road Type	
Regular Forest Service	RF
Forced in Forest Service	FF
Mower Lumber Company	MO

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